THE THREE PALEOZOIC ICE-AGES OF SOUTH AFRICA

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When Mr. Rogers and myself commenced the systematic geological survey of Cape Colony in 1896, we had no evidence before us which would allow us definitely to refer to one period of glaciation in the stratigraphical series. Sir Andrew Ramsay's discovery of ice-action on pebbles in the Permian Conglomerates of Great Britain[1] had been discredited, and the failure of the Paleozoic glacial theory in Europe had been taken to mean that it must be a failure in other parts of the world as well; no matter how good the specimens of glaciated bowlders and the photographs of ice-scored floors, or that came home from India, Australia, or South Africa, no one would believe in the Permian Ice Age. I was myself skeptical when I first came to South Africa, and at a meeting in Cape Town, when some of the glaciated Dwyka Conglomerate pebbles were exhibited, assisted in recording the belief that there was in these scratches no satisfactory evidence of ice-action. I have before me at the Albany Museum some earlier bowlders collected by Mr. E. I. Dunn, together with a slab from beneath the till which is scored by ice, and I do not see how any definite opinion can be derived from them alone.

In the field it is different; there the evidence is overwhelming, as I was soon to see when I joined the Geological Survey later on, but the difficulty is to obtain specimens which in themselves show unmistakable signs of ice-action. When, therefore, I was in due time convinced of the glacial origin of the Dwyka Conglomerate, I could not merely record my opinion that the field evidence was satisfactory; I had to produce specimens which would convince headquarters in Cape Town. I sought for specimens of bowlders which were not only characteristically scratched, but were also faceted. I obtained several in the first year showing three or four definite friction-cut planes on each, all bearing several series of parallel grooves, while the remainders

[1] *Quarterly Journal of the Geological Society*, London, 1855, pp. 185–202; *ibid.*, 1894, p. 463.

of the bowlders were rough and water-worn.[1] The inability of the mind to imagine natural causes for the production of thse facets, other than that which assumes that the foot of a glacier held the bowlders firmly against the floor as the ice moved onward, and ever and again allowed the bowlder to slip and turn slightly, has been sufficient to convert most skeptics to belief in the glacial origin of the Dwyka Conglomerate, and for ten years Mr. Rogers and myself have been slowly converting to this view the travelers who enter the country at Cape Town, culminating in the visit of the British Association last year.

The Dwyka Conglomerate, and its equivalent in Australia and India, is too well known now to require description here, but I have introduced the account of the part which Mr. Rogers and myself played in the elucidation of the problem in order to show the credentials with which we offer evidence of two more glacial periods in South Africa. The evidence of each was discovered by Mr. Rogers; the evidence of one, probably Devonian in age, I have examined in the field;[2] the other is probably Archean, and although I have not seen the glacial beds in place, the specimens which Mr. Rogers has sent me afford ample material for confirming his interpretation.[3]

The rocks of South Africa may be divided into a Pal-Afric and Neo-Afric series, the latter beginning about the close of the Silurian or commencement of the Devonian period, and lasting up to the time of the Kimberley and Stormberg volcanoes, say, to the Jurassic period. The Pal-Afric rocks are pre-Devonian. The resemblance of some of them to the Lake Superior Archean rocks has suggested a like age for them.[4] The enormous displacements they have been

[1] *Annual Report of the Geological Commission*, 1896 (Cape Town, 1897), p. 28; *ibid.*, 1897 (Cape Town, 1898), p. 41; *ibid.*, 1899 (Cape Town, 1900), p. 13.

[2] A. W. Rogers and E. H. L. Schwarz, "Report on the Cederbergen and Adjoining Country," *Annual Report of the Geological Commission* for 1900 (Cape Town, 1901), p. 79; A. W. Rogers, "On a Glacial Conglomerate in the Table Mountain Sandstone," *Transactions of the South African Philosophical Society*, Vol. XI, pp. 236–42 (Cape Town, 1902); *ibid.*, Vol. XVI, pp. 1–8 (1905).

[3] A. W. Rogers, "The Campbell Rand and Griquatown Series in Hay," *Transactions of the Geological Society of South Africa*, Vol. IX, pp. 1–9 (Johannesburg, 1906).

[4] E. H. L. Schwarz, "The Transvaal Formation in Prieska," *Translations of the Geological Society of South Africa*, Vol. VIII, p. 95 and p. lxiii. (Johannesburg, 1905)

subjected to, the vast extent of the volcanic rocks injected through them, the number of successive periods of vulcanism and the greatness of the unconformities between the several members of the Pal-Afric series, and between it and the Neo-Afric series, all tend to establish a great age for the Pal-Afric rocks. Leaving out the Barberton and Witwatersrand beds, which do not concern us here, the later beds may be classified as follows:

Matsap or Waterberg Series
Ongeluk Volcanic Series
Griquatown or Pretoria Series (with glacial beds).
Campbell Rand Series
Black Reef Series
Pneil Volcanic Series

Possibly there is a second quartzite series, the Keis series, below these.

The Pal-Afric rocks end on a line running roughly northeast-southwest, south of which they are covered by the Neo-Afric beds. On the northeast and southwest, however, the older rocks bend round to embrace the younger ones round the rim of a basin-shaped depression, and they were probably at one time continued right round the southern limit of the Neo-Afric beds as well. We can, indeed, find some evidence for two lines of older elevation, both of them running northeast-southwest, the more northern of the two following the northern rim of the Karroo, and the more southern one continuing the Madagascar ridge southward along the margin of our coasts. At first there was a sinking where the southern shores of South Africa now lie, and in the comparatively narrow strait thus formed the coarse-grained, intensely false-bedded table mountain sandstone was deposited. A deepening of the basin allowed the settlement of the Bokkeveld beds with their Lower Devonian fossils. Then came the Witteberg quartzites, with Lower Carboniferous plants, the Dwyka, Ecca, Beaufort, and Stormberg beds. We may tabulate the Neo-Afric beds thus:

DRAKENSBERG LAVAS

Stormberg Series	Rhaetic
Beaufort Series	Triassic
Ecca Series	Permo-Triassic
Dwyka Series (with glacial beds) . .	Carbo-Permian
Witteberg Series	Lower Carboniferous
Bokkeveld Series	Lower Devonian
Table Mountain Series (with glacial beds) . .	? .

The full conformable series is found only on the south; on the north, the series begins with the Dwyka Conglomerate, here a subaërial deposit, which can be followed southward along the rim of the structural basin to where it is essentially a subaqueous deposit, and the Witteberg, Bokkeveld, and Table Mountain beds may be seen coming in successively beneath it. The Stormberg beds, again, are only found in the east.

The Griquatown beds are a highly ferruginous series of shales and slates, sometimes moderately soft and unaltered, when the characteristic color of the whole is blue-black, and the fissures are filled in with blue asbestos or crocidolite. But more often an intense alteration has taken place, and the rocks have become jaspers and quartzites, heavily charged with hematite and magnetite, and the crocidolite has been changed to the quartz pseudomorph, the beautiful honey-yellow tiger eye. Near the top of the series, in the district of Hay, west of Kimberley, there is the well-developed glacial till, the matrix now converted into a red jasper; yet the bowlders of chert, when weathered out, show the unmistakable faceting and scratching which can have been caused only by glacial action. The freshness of the appearance of the ice-scratched bowlders is the more remarkable when one realizes that not only the matrix, but the inclusions as well, have been indurated by metamorphism. The size of the bowlders varies up to two feet, and they are scattered at random through the matrix, to which they bear a very small proportion in regard to bulk; but occasionally there is a small bed of pebbles or coarse grit. Mr. Rogers records at one locality a number of "Dreikanters," but I do not know whether anything additional can be learned from them. I have found them in large numbers in some of the Witwatersrand conglomerates. The whole thickness of the glacial till is probably under 100 feet, but the extent of country covered by it in the area already mapped is over 1,000 square miles.

The Table Mountain sandstone glacial bed is very similar in position and character, though not of course in metamorphism, to the Griquatown one. When the Geological Survey commenced operations, there were two series of quartzites, the Table Mountain and the Witteberg, which had been mixed up, so that, in order to find some way of either distinguishing or definitely joining up the

two, I took the two series bed by bed. I found that both series were characterized by a shale band near the top. In the Table Mountain bed, when it became clear that this series underlay the fossiliferous Devonian Bokkeveld beds, I hoped to find some organic remains, and searched some good exposures in Ceres District fairly thoroughly, but I never came across any bowlders in it. It was not till several years afterward that we found the ice-scratched bowlders in the same bed and along the same range of mountains.

The Karroo in the southwest is bordered by ranges of mountains which run east and west along the south, and north and south along the west, meeting in a great knot, perhaps as good an example of Suess's *Schaarung* as exists anywhere. The folds of the southern ranges have been huddled against granite bosses by pressure from the interior, and the rocks have been so compressed that it is hard to distinguish separate beds; on the east, where the granite ends, and the folds have had room to expand seaward, the shale band at the top of the Table Mountain series is again apparent. Owing, however, to the nature of the rock in this band, which allows its more easy disintegration, as compared with the quartzites above and below it, it is, wherever I have seen it, covered with débris, so that I cannot say positively that the glacial beds do not extend eastward, but I do not think they do.

Following the shale band northward of the junction knot of mountains, the rocks composing it consist of soft slates very finely laminated in places. The quartzites above it are about 500 feet thick, while the band of shale perhaps might be put down at 300 feet, the whole Table Mountain series being estimated at 5,000 feet. The mountains soon become exceedingly rough and difficult of access, and the slopes become cumbered with débris. Broadly, the mountains are formed by an S-shaped bend, the anticline on the Karroo side, constituting the Cederberg Range, and the syncline holding in its embrace the valley of the Olifants River. At a certain point in the Cederbergen, the Cape Ceder, *Callitris* (*Widdringtonia*) *juniperoides* is found growing, but not south of this, nor, indeed, anywhere else in the world. Up to this point, from the south, the shale band is not conglomeratic, and in the first road-cutting north of this point the shale band does contain ice-scratched

bowlders. As there is no other difference in the nature of the rock north and south of the point, nor is there any difference in the ele-

FIG. 1.—The Witzenbergen, from the top of the Schurftebergen, showing the steeply inclined Table Mountain sandstone near the head of the Witzenberg Valley, and the shale band at the top of that rock series. Ceres Division, Cape Colony.

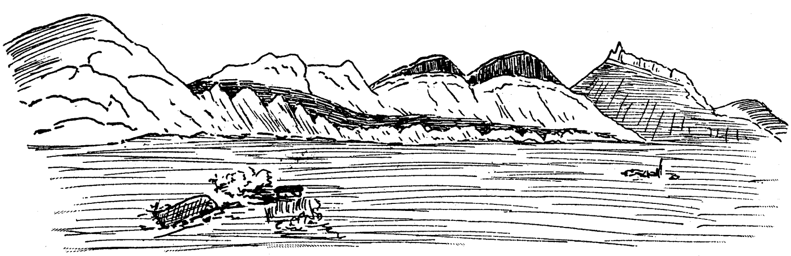

FIG. 2.—The shale band in the Table Mountain sandstone, a little south of where it becomes conglomeratic. The foreground is made of Devonian slates. The reduplication of the shale band is due to a sharp fold, and on the right a sudden change in the strike is seen. The Cold Bottweld, Ceres Division, Cape Colony.

vation or structure of the mountains, or of the rainfall upon them to account for the cedars stopping at this point, one is left, by the process of elimination, to somehow connect the distribution of the trees with that of the glacial conglomerate.

A typical section of the shale band on the Clanwilleain side of the Cederbergen gives:

Shale	200 feet
Shaly conglomerate	20 feet
Conglomerate	100 feet

The conglomerate is a mudstone containing pebbles and bowlders up to fifteen inches in diameter. The latter consist of quartz, three distinct varieties of quartzite, sandstones, felspathic grits, diabase, amygdaloidal melaphyre and granite, and are well faceted, and the closer-grained ones strongly and characteristically scratched. North of Clanwilleain, the Table Mountain sandstone rapidly thins out, and the upper beds one by one drop out till, in Van Rhyn's Dorp, the Dwyka Conglomerate is separated from the Pal-Afric beds by only a few feet of quartzite, and in Bushmanland rests directly upon them. There may be a locality where the Permian glacial beds rest directly on the Devonian ones, but we have not found such a one. Apart from stratigraphical evidence, it would be extremely difficult to separate the two; the only difference we could find—and it amounts to very little—is the presence of quartz pebbles in the Table Mountain conglomerate.

The area of the Devonian glacial beds is uncertain. The actual outcrop from which bowlders have been obtained is 23 miles long, but the ends plunge under débris and are certainly continued north and south. Eastward the limb of the great Cederberg anticline dips under the Karroo beds, so that it is uncertain how far the glacial beds extend in this direction. We find bowlders of Table Mountain sandstone brought up from great depths in the agglomerates in the Sutherland volcanoes, right in the deepest part of the Karroo sinking, but we can naturally see nothing in them which would help us in tracing the glacial beds. On the east, where the Table Mountain sandstone comes again to the surface in Pondoland, we have not been able to trace the shale band, nor have geologists recorded it in Natal.

At some future date it will perhaps be established that there is a rhythmic recurrence of glacial conditions in subtropical and even tropical countries, and we shall be able to date the rock strata according to the positions of these tills. In Australia they have two—the

Permian or Carbo-Permian, and the so-called Cambrian one, which is, at any rate, older than the Ordovician, and possibly Algonkian.[1] We have three in South Africa, the oldest of which may be equivalent to the older of the two Australian ones. The great importance of our two older bowlder clays is that they are not mere chance moraines that have somehow become preserved, and which might have formed on lofty mountain ranges, as moraines now form under the Equator in South America, and therefore are no indication whatever of changes of climate or of the sun's heat. Both our Table Mountain and Griquatown glacial beds occur interstratified with undoubted subaqueous deposits, and themselves show evidence of subaqueous origin. The prevalence of glaciers down to the water's edge in South Africa is undoubted, and both the older, as well as the Permian, conglomerates clearly point to rigorous climatic conditions.

Sir Andrew Ramsay's evidence as to the European Paleozoic Ice Age,[2] and the character of the striations on the stones, is admitted, even by those who do not accept his explanation, to be strongly suggestive, and had Sir Andrew Ramsay stopped at this, his theory, perhaps, by now would have been accepted; but he attempted more. He believed that he could trace the origin of the pebbles and bowlders to the Silurian hills of north Wales, and he concluded that they had been transported by floating ice connected with glaciers which existed among those mountains in the Permian period. It was, however, easily demonstrated that the blocks need not have been transported from afar; the ridge of old Paleozoic and pre-Cambrian rocks which has been exposed in the Charnwood forest area may very well have been the parent source of the inclusions. The breccias, again, instead of becoming coarser nearer the source attributed to them by Sir Andrew Ramsay, as was required by his theory, were found to become so as they were followed to the east and south-east. As far as I can gather, the Paleozoic Ice Age theory in Europe

[1] W. Howchin and J. W. E. David, *Report of the Australian Association for the Advancement of Science*, Vol. IX (1902), pp. 194–200.

[2] "On the Occurrence of Angular, Sub-angular, Polished and Striated Fragments and Bowlders in the Permian Breccia of Shropshire, Worcestershire, etc., and on the Probable Existence of Glaciers and Icebergs in the Permian Epoch," *Quarterly Journal of the Geological Society*, 1885, p. 185.

has been discredited on the failure of a non-essential feature in the original exposition, and the whole question calls for re-examination. And not only the Permian breccias, but conglomerates and breccias of all ages, even in the zone of intense metamorphism, require to be minutely and critically studied; for, as our South African bowlder clays show, the striae and faceting characteristic of ice-action may be preserved in the most unexpected way.